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# The effect of margin thickness, degree of convergence and bonding interlayer on the marginal failure of glass-simulated all-ceramic crowns

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ABSTRACT

The objectives of this study were to identify the effect of design parameters, namely marginal thickness, degree of convergence and the different interfacial conditions, on the initial failure load that induces cracking from the margin in glass-simulated dental crowns. Crown-like glass cylinders were prepared to simulate posterior all-ceramic crowns with two different marginal thicknesses (0.8 or 1.2 mm) and degrees of convergence (6° or 12°). A three-step bonding system was used complementarily with a silane coupling agent to adhesively bond the specimens to resin dies. The crowns were subjected to an axial applied load to generate hoop tensile stress at the crown margin. The entire loading and fracture processes were recorded by video camera. The loading data were compared with the other two interfacial treatments (Vaseline grease and directly poured uncured resin on glass). The Weibull distribution was used to statistically analyze the characteristic failure load and the mean values. The fracture surfaces were fractographically analyzed along with the load–displacement curves, and the degrees of crack stability for each parameter were also identified. It was found that there is no difference in the initial failure load between the different marginal thicknesses in all interfacial conditions. The bonded crowns present more resistance to crack propagation. The higher convergence crown preparation can reduce the initial failure load at the crowns' margin, which can be resisted by a strongly bonded interface. Clear interactions between margin design parameters and their effects on the stress development and crack propagation are necessary to develop an appropriate design of all-ceramic crowns.


## 1. Introduction

Ceramic coatings have great versatility and have been used in many fields [1–4] because of their satisfactory physical properties and improved functionality. In dentistry, all-ceramic restorations have become more popular as a restorative option; they can sustain multidirectional chewing forces, reduce plaque accumulation and importantly provide excellent esthetic outcomes. However, due to their brittleness, all-ceramic prostheses are usually susceptible to tensile stress, especially in the area where the bulk of the material is not sufficient. For a single crown, the potential sites are primarily the occlusal or the marginal areas, where the space is quite limited by the position of the opposing or adjacent tooth, the remaining tooth structure and the risk of invading pulp vitality. Consequently, the design of all-ceramic crowns, especially for posterior teeth, undoubtedly raises critical concerns regarding both stress distribution and the vitality of the remnant tooth structure.

The situation is even more complicated when monolithic ceramic crowns are supported by dentin forming a complex bilayer or trilayer structure, especially when a tough but opaque ceramic coping is additionally introduced as a crown's substructure aiming to provide support for veneering porcelain. In addition, clinical crown failure origins have been variably reported (such as the occlusal contact area or wear facet [5,6] and coping–veneer interface for bilayer crowns [7,8]; these are sometimes considered to have multiple origins [9]) and may be affected by competing fracture modes that can be dominant under certain conditions. For these reasons, perfect design preparations for all-ceramic restorations have not been developed. Despite this, studies of a hard contact on the failure of flat glass bilayer or trilayer specimens have brought considerable understanding of the failure from radial cracking or cone cracking and have been useful to explain chipping, impact fracture of the veneering porcelain or catastrophic failure of the monolithic crown. The test has some limitations regarding the behavior of clinically failed crowns because of the simpler shape of the tested specimens and the dominant role of local contact failure.

Crown fracture resistance tests undertaken by applying an axial or non-axial force on anatomical crowns monotonically [10–14] or cyclically [15,16] until the crowns fracture or the first sign of

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chipping occurs have been increasingly developed to identify the potential design parameters that affect the crowns' performance. These test results, however, still present considerable scatter, extremely high reported failure loads (relative to oral forces) and different failure characteristics from what occurs clinically. Also the local contact failure modes are still dominant and the applications are then only limited to a comparison of the design features, which cannot be directly compared to the loading results with the crown's performance in the clinic. To increase the reliability of such a test, an additional fractographic interpretation of the fracture surface is recommended and the test should present similar patterns of crack propagation as observed with clinically failed crowns [17]. However, due to limitations in simulation of the entire oral condition and complex chewing patterns of the test, each type of failure and associated complex stress condition within the crown should be simplified and separately considered in any in vitro test. This will facilitate identification of the role of various design parameters within the model that can more faithfully represent the situation related to clinically failed crowns.

Many design aspects have already been proposed in the literature, such as occlusal porcelain thickness [18–20], axial wall height [21–23], coping–veneer thickness ratio, the effect of margin design [24–27] and degree of convergence [26,28,29], etc. Among these, the failure load response regarding the convergence degree and marginal configuration are still controversial. These observations lead to uncertainty as to the amount of tooth structure to be removed during clinical preparation. As has been mentioned earlier, unlike clinically reported crown failures, the specimens used in most laboratory studies are usually of contact-induced failures when the crowns are loaded with a hard metal. This localized loading and stress condition may not place the crowns' margin into the highest tensile stress state. Additionally, the criterion used to identify whether specimens have failed appears to be different from study to study [30–32]. For instance, the failure load is usually recorded as the first load drop presented in the associated load–displacement curve [32–35]. It was previously found in our observations that the catastrophic failure load is not sensitive enough to capture the first sign of a crown's failure and thereby provide accurate results for the tested parameters.

Based on the clinical reports of the marginal failure of posterior all-ceramic crowns and with the clear assistance of fractographic features of fractured glass domes, the crack would potentially originate from the crown's margin when the crowns were loaded with a compliant indenter or off-axis loading, or from the concavities at the proximal margin of crowns [36]. By considering the effect of a hoop tensile stress developed by a compliant indenter, a simple relationship between the thickness, size of glass dome and failure load to initiate so-called "channel cracks" from the specimen's margin was established and firstly used to predict the potential force to develop a crack in tooth enamel [37–39]. This interesting idea may also be applicable for exploring the different designs of all-ceramic posterior crowns, which invariably have some degree of convergence and a complex cement–crown interface.

Interestingly, some effects of resin strengthening of dental porcelain to increase the crowns' failure resistance and the favorable failure response of the porcelain crowns when they were resin bonded have been proposed in many laboratory studies [35,40–42]. Many theoretical concepts of resin strengthening glass and dental porcelain have been proposed, such as crack blunting, additional energy dissipation and crack closure [43–46]. However, the basic mechanics for such behavior have yet to be demonstrated, partially due to the complexity of the interface including dental porcelain, cement and bonded substrate.

In our previous study, the initial failure loads of cylindrical glass-simulated dental crowns that induced the first marginal crack were analyzed and compared between the different geometries (6 or 12 convergence degrees and 0.8 or 1.2 mm marginal thickness) as well as the two different interfacial conditions between the glass and resin die. In the first group, where Vaseline grease was applied internally to represent the situation of a debonded crown with some space present at the interface, the stress response inside the crown was primarily affected by the geometrical effect. In the second group where the uncured resin was poured directly into the glass surface, even though it can represent the situation of higher surface contact between the resin die and glass, the crowns do not develop a strong bond between glass and resin die and may be affected by some polymerization-shrinkage-induced compressive stress developed inside the crown during the curing process. For the sake of comparison, a third scenario has been generated here to see the geometrical related stress response by introducing an additional resin interlayer between cured resin die and glass-simulated dental crown to represent the situation of a stronger bond with minimal polymerization shrinkage.

The aim of this experimental study is then to compare the initial failure loads to induce marginal cracking of glass-simulated dental crowns variably bonded to resin dies with different design geometries (namely marginal thickness and degree of convergence) and to explore the propagation patterns of these marginal cracks by using glass-simulated dental crowns under the influence of an axial-load-induced hoop circumferential tensile stress.

## 2. Materials and methods

In this study, the initial failure load that induces marginal cracks of adhesively bonded glass-simulated dental crowns was analyzed and compared with the existing laboratory data from the previous study regarding the different design parameters and the interface conditions. Additionally, the crack propagation behavior (stable or unstable) was also identified and complemented with fractographic identification of the fracture origin.

### *2.1. Preparation of glass-simulated dental crown*

Crown-like glass cylinders were prepared from Borosilicate glass tubes (10 mm diameter and 2.25 mm wall thickness). The tubes were cut to 11 mm length with a precision water-cooled diamond saw (Isomet, Buehler Ltd, Lake Bluff, USA).To remove the large defects generated from cutting and to control the surface roughness (defect size) of the base of the margin, the specimens were positioned in a special holder, polished with a #400 grit diamond wheel (Flexovit Abrasive, Victoria, Australia) and water in a polishing machine (Beuhler UK Ltd, UK) (300 rpm).

A custom-made water-cooled diamond bur milling system was developed in this study to fabricate the glass crowns with controlled geometries. The two different degrees of convergence (6° or 12°) and two marginal thicknesses (0.8 or 1.2 mm) were generated by a round end taper diamond bur mounted in a high-speed hand piece positioned in a micro-adjustable small bench lathe (Fig. 1). The length of the milled surface was 8 mm, which is equal to the bur's length. The total height of the glass specimen was 10 mm, similar to the length of a dental crown. The glass specimens were then ultrasonically cleaned in 70% ethanol and air-dried. An additional five specimens for each design were prepared and included in the bonded group to compare with the existing test data of the same geometrical set with and without a Vaseline interlayer.

### *2.2. Resin die preparation and surface treatment*

The resin dies were fabricated by a mold-forming technique using milled glass as the mold. The glass specimens were placed